

DQM Information Paper 3.1.3 Conductivity/Salinity Measurement Principles and Methods

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1.0 About this Information Paper

(This section is essentially common to all DQM Information Papers. If you have seen it already, please skip to Section 2 below). This Information Paper is a new type of guidance. It has been created for our new integrated system of guidance and tools for water quality monitoring called “the Data Quality Management (DQM) System”. DQM is implemented by the Clean Water Team (CWT) where needed to support collection of **reliable** data of **known quality** in a fully documented, **scientifically defensible** manner. Most DQM materials are delivered in Parameter-Specific Folders, which provide both the traditional “protocol” materials and new, expanded guidance in three types of inter-related documents: Fact Sheet, Information Paper, and Standard Operation Procedures. Background information on the ecological significance of each parameter and the regulatory benchmarks that have been developed for it is summarized in the FACT SHEET. The technical information on measurement methodology provided in this IP with its method-menu. Then there are several detailed standard operating procedures (SOPs) that provide step-by-step instructions for each instrument or kit, as well as instrument-specific Quality Assurance/Quality Control and CCRR directions and data validation checklists.

This Information Paper (IP), a part of the Parameter-Specific Folder for conductivity and salinity, provides “big picture” technical information on measurement methodology. If you are a Trainer or a Technical Leader of any monitoring project, this may help you select a good method to measure conductivity or salinity in your water body.

Section 2 of this IP introduces a "method menu" table with a list of kits and instruments commonly used by citizen monitoring groups, agency staff, or laboratory technicians, with information on the limitations, approximate cost, measurement range and resolution, and associated labor of each device. Next (Section 3), a description of the different physical or chemical principles underlying the commonly used methods to measure conductivity and salinity is provided. Section 4 provides practical tips and advice on conductivity and salinity measurement based on our cumulative experience (The Clean Water Team and others). This section is meant to be updated as we learn more. Finally, the “Sources & Resources” section (Section 5) provides a list of available SOPs as well as contact and website leads into further information.

2.0 Ways to Measure Conductivity

Table 3.1.3-1 shows types of commonly used methods for measuring conductivity and salinity; please seek more information on specific kits. You can use it during the initial phases of your group’s monitoring activities. Once you have formulated the monitoring question, decided

Table 3.1.3-1 Selected Methods for Measurement of Conductivity and Salinity

| Code (Note a) | Principle | Device | Range | Resolution | Cost | Labor | Applications | Extent & Sources of Error (percent of measured value) |
|------------------|------------------------|------------------------------|----------------------|---------------------|---------------------------------|-------|---------------------------------------|---|
| EC | Electrical conductance | Conductivity meter | 0 to 200 microS | 1 microS | \$60 | 2 min | Snowmelt, rainwater | ±5% uncompensated temperature effect Drift, source of Standard |
| EC | Electrical conductance | Conductivity meter | 0 to 1990 microS | 10 microS | \$60 | 2 min | Freshwater | " |
| EC | Electrical conductance | Conductivity meter | 0 to 19.90 milIS | 100 microS (0.1 mS) | \$60 | 2 min | Freshwater, Brackish water | " |
| ECP | Electrical conductance | Sonde/data logger probe | var | var | ~\$4,000 for entire Sonde | 2 min | all | ±5% Drift, source of Standard |
| SAL | Electrical conductance | Salinity probe | 2 to 40 ppt (Note b) | varies | Part of a package \$800 or more | | Brackish and Seawater | ±5% Drift, source of Standard |
| REF | Refractive index | Refractometer | 2-100 ppt (Note c) | 1 or 2 ppt | \$150 | 1 min | Brackish, Seawater, hypersaline ponds | ±10% |
| HYD | Specific gravity | Hydrometer | 16-40 ppt (Note d) | 1 ppt | \$10 | 1 min | Brackish and Seawater | ±10% |
| HYD | Specific gravity | Hydrometer | 2-100 ppt | 1 ppt | \$30 (inc jar) | 3 min | Brackish, Seawater, hypersaline ponds | ±5 |
| | Gravimetric | Total dissolved solids (TDS) | all | 0.1 mg/l | Lab method | | | ±5 |

Notes: (a) The Codes on the left are consistent with the Instrument codes used in all other DQM materials.

(b) This device calculates salinity from conductivity measurements and provides the output as parts per thousand (ppt), also known as promil, equivalent to gram per liter (g/l).

(c) This device overlays the refractive index scale on a scale of corresponding salinity and provides the output in ppt.

(d) This device calculates salinity from water density measurements and provides the output in ppt.

which parameters you need to measure, developed your sampling design, and determined how much error you can tolerate in your measurements, you can refer to this menu again and find the device that will work for you

3.0 Principles and Applications of Conductivity/Salinity Measurement Methods

3.1 Total Dissolved Solids (TDS)

The most straightforward way to measure the concentration of salts and other solids dissolved in a water sample is to remove all the particulate matter, take a known volume of the filtered water, dry it inside a porcelain container, weigh the dry container with the salt in it, and subtract the weight of the empty container. The results are expressed in mg/l. A serious limitation of this method is that it will include any dissolved solid, whether it is salt or not, in the TDS value. Another limitation of measuring TDS by this gravimetric method is that it requires laboratory facilities and many hours of drying time. The term TDS is mostly used for freshwater, but the concept of expressing the weight of salts per a volume of water is the same as in the term "salinity", used predominantly for brackish or seawater in units of gram per liter (g/l, equivalent to parts per thousand (ppt), also known as promil). The reader is referred to Section 4.6 of this document for further discussion of the relationship between TDS and conductivity.

3.2 Electrical Conductivity

Electrical conductivity measurements are focused on salts - or their ions when dissolved in water - which are conductors of an electrical current. Conductivity is measured by a probe that applies voltage between two electrodes, spaced a known distance apart, and records the drop in voltage. This drop reflects the resistance of the water, which is then converted to conductivity. Thus, conductivity is the inverse of resistance and is measured in the amount of conductance over a certain distance. The conductivity units are called "mhos" - the reciprocal of "ohms" used to measure resistance. For most natural waters, the units of mhos/cm are too large, so conductivity is reported as micro-mhos/cm where 10^6 micromhos is equal to one mho. Sometimes the units are expressed as microSiemens: 1 microS is equal 1 micromhos/cm.

Electrical conductivity depends on the identity of the ions in solution and their activity. Activity depends on temperature. In a single salt solution, a conductivity probe will yield different values at different temperatures, in theory showing a linear plot (Figure 1, top panel). In practice, a probe without automatic temperature compensation yielded a curve that was very similar to the theoretical curve, and a conductivity meter with built-in automatic temperature compensation (ATC) feature approached a horizontal line (Figure 1, bottom panel) but is still away from fully compensated values. Operators are therefore encouraged to calibrate their EC meters at temperatures as close as possible to the ambient temperature they are expecting in their Stations.

3.3 Light Refraction: Refractometers

Salts and other solids dissolved in water alter the way water refracts light that goes through it. The extent of change in the refractive index is related to the concentration of solids in the water. The refractometer is based on this principle: it provides a scale of salinity, in the conventional units of g/l (ppt), on the plane that shows the location of the "break" in the light as a function of refraction index.

3.4 Specific Gravity: Hydrometers

The specific gravity, or density, of water is higher when the dissolved solids (salt and other substances) in the water is higher. The specific gravity is measured by a floating device called a hydrometer. It is essentially a glass tube, sealed with air in it, which is suspended upright in the water due to a prominent weight at the bottom. The extent of the tube's submersion in the water (which is a function of the specific gravity of the water) can be read on a scale placed inside the tube. In some hydrometers, the results are given in specific gravity in the range of 1.000 to 1.070; these values are converted to salinity in the range of 0 - 100 g/l (ppt).

4.0 Practical Advice and Tips

4.1 What to expect out there

Salt concentrations in water in Nature range from virtually zero (pristine rainwater) to over 27 percent (i.e., if you dry 100 ml of water you end up with 27 grams of salt). If we translate this to "microsiemen equivalents", we are looking at a range of 1 to 600,000 uS. Choosing the right instrument is obviously important. In Utica Reservoir with its granite watershed and snowmelt water, it was possible to identify the source of slightly saltier water by tracking a gradient between 3 uS and 7 uS (and each 1-uS increment was meaningful). In San Francisco Bay Area urban creeks, on the other hand, resolution of 10 uS was usually adequate, and error of plus-or-minus 30 uS was OK, because dry-weather conductivities ranged between 700 and 1600 uS. Resolution of 10 uS can even let you check whether the rain in your area is polluted (normally it was 30-40 uS, but got down to 10 uS after El Nino rains), however in this case the measurement error will be driven by resolution and will be very high. If you are monitoring estuaries, tidal wetlands, or inland seas in California you are likely to need an arsenal of instruments!

4.2 Quality Control, Check, Record, and Report (CCRR) guidance for conductivity

(This paragraph is essentially common to all DQM IPs. If you have seen it already, please skip to Section 4.3 below) The DQM guidance and tools provide ways to Control, Check, Record, and Report (CCRR) the quality of numerous water quality measurements. Essentially, "**Control**" is about things we can do to affect and improve data quality. "**Check**" is about testing how good a measurement actually is. "**Record**" is about the language we use to express the results of our quality checks and about entering our findings into the "placeholders" on DQM forms or spreadsheets. "**Report**" is about the way we calculate the measures of quality, i.e., the data

quality indicators, so they can be shared with others. Specific CCRR procedures are added on top of the generic quality assurance procedures such as keeping everything clean, waiting for stabilization of the reading, and keeping good records. Because each type of instrument or kit requires its unique CCRR actions (that cannot be generalized for all measurement devices), the step-by-step instructions for these actions are provided in the instrument-specific standard operating procedures (SOP). For conductivity, detection limit per se is not really applicable but folks sometimes use it to indicate the lower end of measurement range.

4.3 All about Standards and NIST-traceable (Certified) Standards

(These four paragraphs are common to other Parameter-Specific DQM IPs that refer to Standard Solutions. If you have seen them already, please skip to the last – fifth - paragraph of this Section). Instrument calibration is adjustment of the output to reflect the reality, as defined by a “Standard”. Instrument accuracy checks – done for devices for which you cannot tweak the output – provide for “correction” of the output based on comparison with reality, as defined by a “Standard”. In both and all other cases, the accuracy of any measurement depends on the Standard that is used to assess how close the measurement was to the “True Value” (i.e., as close as it gets to the absolute truth. But how do we protect and assess the accuracy of the Standard itself? Standard solutions do change and deteriorate over time.

Another unfortunate fact is that different manufacturers of Standard solutions and buffers sell solutions that sometimes differ in their conductivity or pH value to begin with. The only way to cope with this is to assign a unique Standard ID to each bottle, to carefully document all the information related to that Standard, and to specify the Standard ID when recording instrument calibrations (see DQM Project File for placeholders and SOP-9.2.1.2(Calib) for detailed instructions). It also helps to bring your instruments and “Resident” Standards to regional inter-calibration events (a.k.a. “instrument calibration parties”) and compare them with “External” Standards.

We are still left with the question “How do we know which Standard is more accurate?” for which we need to refer to the National Institute for Standards and Technology (NIST) and other organizations dealing with Standards (e.g., ASTM). Fortunately, NIST has developed a set of Standard solutions (that everyone refers to as “the truth”) and highly-detailed recipes for preparation of these Standards. Today, many Standard manufacturers make Standards that are “NIST-traceable” or ASTM-traceable” by using these recipes to the letter and/or by comparing the batches of solutions they make with Standard solutions distributed by NIST or ASTM. Thus, “**Certified Standards**” include any Standard that is traceable to NIST or ASTM. Resident and External Standards can all be Certified Standards as well. A Certified Standard is considered the “ultimate authority” if valid, i.e., if the bottle was (a) used before the expiration date; (b) has been stored tightly capped; and (c) has not been exposed to extreme temperatures.

The CWT Coordinators are using Certified Standards when participating in instrument calibration events, and our DQM Project File has placeholders for the NIST or ASTM reference information. Certified (NIST-traceable or ASTM-traceable) Standards can also be purchased directly, but they are more expensive than the generic Standards. Making your own Certified

Standards using recipes is a good option only if you have access to a laboratory with analytical balance, Reagent-grade salts, high purity water, and an expert chemist who knows how to handle anhydrous reagents through desiccators & temperature shifts and do the right calculations with formula weights of hydrated salts.

Conductivity standards are inorganic salt solutions and they are usually stable over time; however they may drift away from their original value. Drift can happen if Standards are allowed to evaporate or – in the case of highly concentrated Standard – to absorb water when exposed to air. To minimize the error introduced by this drift, it is recommended to avoid exposure to heat, to store well capped, and to use within expiration date.

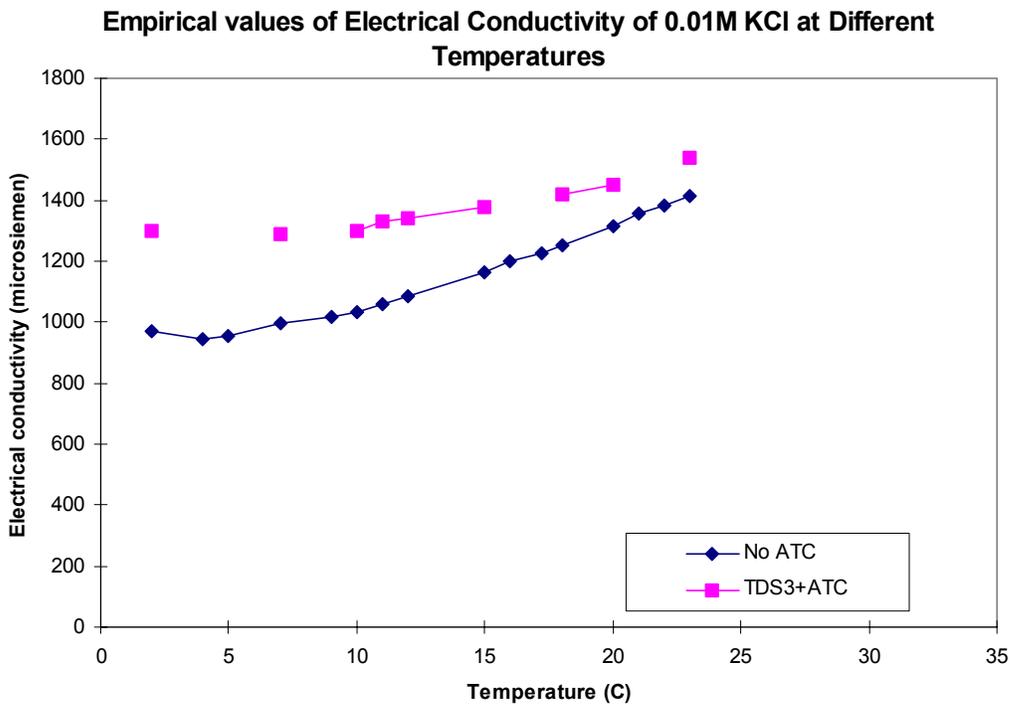
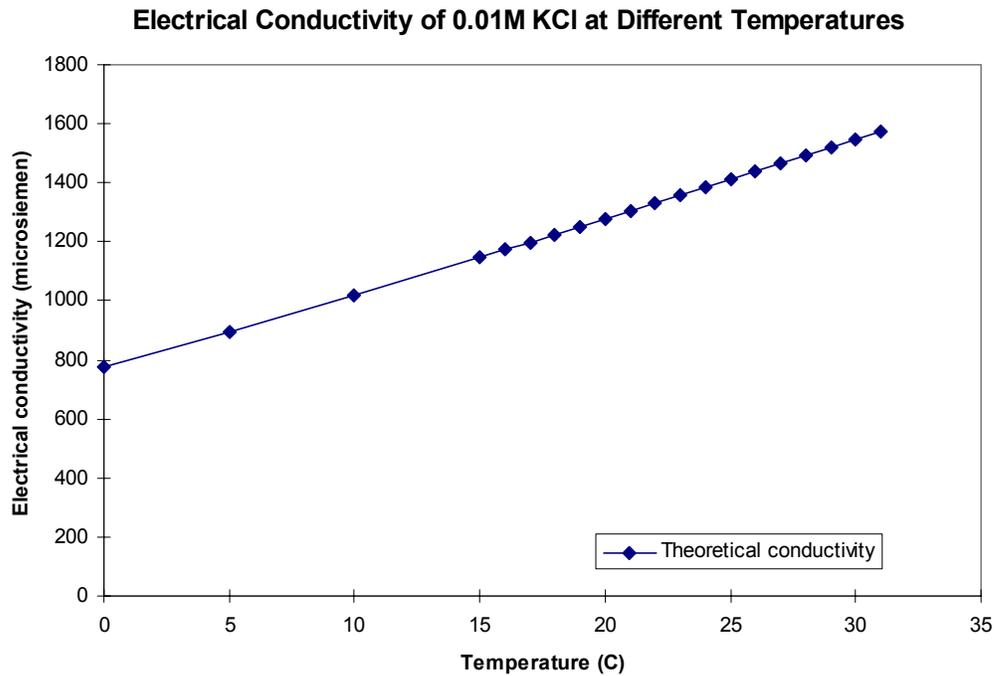
4.4 Manual versus automatic calibration

Calibration (i.e., adjustment of the reading) of a conductivity meter while immersed in a standard solution is fairly simple, involving turning a calibration screw. Automatic calibration may be faster but is more complex, and care should be given to assuring that the Standard used indeed has the value that has been specified by the manufacturer.

4.5 Temperature during calibration

The temperature of the Standard during calibration is very important, because conductivity is highly dependent on temperature. For routine monitoring when a conductivity meter is used only by one crew, the calibration should be done at ambient temperature. However, in situations where many crews are using the same instrument sequentially (typically for mass monitoring events, e.g., snapshot monitoring day), it is recommended to calibrate at 25 C every time so all users will have the same reference point for the instrument drift. One way to calibrate at 25 C is put the standard in a small cup and heat it in your hands, checking the temperature continuously until it reaches 25 C. Then you can dip the conductivity meter, check the reading, and adjust it if necessary. Figure 3.1.3-1 shows how the temperature can affect your conductivity measurement result. The top panel shows the theoretical conductivity values of the Standard, (0.01N KCl), as a function of temperature. The bottom panel shows empirical results obtained with two types of conductivity meters, one that has a built-in automatic temperature compensation (ATC) device (it is a chip that applies a correction factor of 2% per degree C), and another that does not have ATC. The empirical plots show that with ATC the reading is not “fully corrected” and may be off by up to 100 uS at temperatures commonly measured in our creeks.

Figure 3.1.3-1 Relationships Between Conductivity and Temperature



4.6 Accuracy checks for Refractometers and Hydrometers

In the case of built-in scales such as in the hydrometer or the Refractometer, the user cannot adjust the output, only record the reading of a standard solution. The manufacturer's calibration is what you have, and it is a good idea to purchase devices that are sold with documentation of calibration records. However, a Standard Solution is very important in providing an “accuracy check” for the device, i.e., to check if it gives the reading it is supposed to give. If a device is found to be “off”, it may be a good idea to discard it (except for desperate situations where the user may record how far off it was from the standard value and correct the data for that bias).

4.7 Relationship between Conductivity and Total Dissolved Solids (TDS)

The electrical conductivities of a series of salt solutions (of a single salt, for example KCl) correlate well with the concentrations of the salt in these solutions, or - in other words - the TDS or salinity values of that series of solutions. A series of solutions of a different salt will yield a different curve. The conductivity depends on the activity of the ions, not on their molecular weight. Therefore, it is difficult to establish a catch-all relationship, or a universal correlation coefficient, between conductivity and TDS or salinity. However, there are a number of instruments that utilize a correlation coefficient established for a known mix of salts to "translate" the conductivity reading into equivalent TDS or salinity values. For example, there are many pocket TDS-meters that report results in mg/l; these are based on conductivity measurements and multiplication of the values by a built-in factor. In the Salinity/Conductivity/Temperature (SCT) meter, salinity is determined automatically from the meter's conductivity and temperature readings according to algorithms found in Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

5.0 Sources and Resources

This IP is an integral part of the Data Quality Management (DQM) System implemented by the Clean Water Team, the Citizen Monitoring Program of the California State Water Resources Control Board.

For an electronic copy, to find many more CWT guidance documents, or to find the contact information for your Regional CWT Coordinator, visit our website at www.swrcb.ca.gov/nps/volunteer.html

If you wish to cite this IP in other texts you can use “CWT 2004” and reference it as follows: “Clean Water Team (CWT) 2004. Conductivity/Salinity Measurement Principles and Methods, DQM IP-3.1.3. in: The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment, Version 2.0. Division of Water Quality, California State Water Resources Control Board (SWRCB), Sacramento, CA.”

Available SOPs (2004 Compendium)

- SOP-3.1.3.1(EC) Measurement of Conductivity with a Pocket meter
- SOP-3.1.3.2 Measuring Salinity with a hydrometer
- SOP-3.1.3.3 Measurements of Salinity with a Refractometer

References

American Public Health Association (APHA) 1998... Standard Methods for examination of water and wastewater. 20th ed. Washington DC.